XXV.—*On the Geological Distribution of the Rhabdophora.* By Charles Lapworth, F.G.S. &c.

Part III. Results.

[Continued from p. 29.]

Family iv. **Dichograptidæ.**

This important group is at once the most prolific and the most compact of all the families of the Graptolites. Although it contains more than one third of all the recognized genera of the Rhabdophora, no one can turn over the beautiful plates which adorn Hall's classical memoir on the "Graptolites of the Quebec Group," in which the majority of its forms are figured, and fail to be struck with the decided family likeness which pervades them all. The type of calycle remains substantially invariable throughout all its component genera; and I doubt not that the identity of this feature in the compound family of the Phyllograptidæ will eventually compel us to regard it as also naturally belonging to the same subgroup; for its more fully known species are, morphologically, nothing more than *Tetragrapti* whose branches, instead of remaining free, are united dorsally throughout the whole of their extent.

So far as our present knowledge enables us to judge, it appears that the Dichograptidæ constitute the most ancient family of the Rhabdophora. The earliest examples appear in the upper zones of the Lingula flags; and the family includes all the Cambrian forms of Rhabdophora hitherto discovered. Although but few species are yet quoted from these ancient deposits, it is certain that many await discovery; for the family reaches its maximum, both in genera and species, in the lower zones of the succeeding Arenig formation. In the typical beds of this age, as exhibited in the strata of Skiddaw, Scania, and Pt. Levis, all the genera, with but one or two dubious exceptions, occur in association. In the succeeding dark shales, which in Britain and Scandinavia are, at present, provisionally assigned to the Upper Arenig and Lower Llandeilo, few complex genera occur, and some species of the simplest genus *Didymograptus* alone survive; but these are found in incredible multitudes. This genus is represented by an occasional individual as late as the epoch of the Upper Llandeilo (Glenkiln), when the family appears to have become wholly extinct.

Didymograptus &c.—The simplest genus (*Didymograptus*) appears to have been the most prolific of the family, and the most extended in its vertical range. Its oldest known species

(*Didymograptus sparsus*, Hopk., and *D. pennatulus*, Hall) are found in the lowest Arenig strata of St. David's, at the base of the Ordovician of that region. Its most recent form hitherto detected (*D. superstes*, Lapw.) is by no means uncommon in the earlier beds of the Glenkiln (Llandeilo-Bala) shales of South Scotland.

Of this genus several well-marked subgroups are recognizable, distinguishable by the general shape of the polypary; but our knowledge of their range is not as yet sufficient to enable us to draw any reliable conclusions respecting their individual existence in time or space. One group, however —that of *D. Murchisoni* (*geminus*)—is remarkable, as its forms are essentially characteristic of the great dark-shale zone of the Arenig-Llandeilo, in which they are everywhere the preponderating fossils.

Tetragraptus.—The four-armed genus *Tetragraptus*, Salt., stands next to *Didymograptus* in abundance of species and individuals. Its range, however, is peculiarly circumscribed, none of its forms occurring outside the limits of the lower or typical zones of the Skiddaw-Arenig formation, which it characterizes not only in Wales, but also in England, Scandinavia, and North America.

Complex Genera.—Of the more complex genera of the Dichograptidæ we recognize two artificial groups, viz. (*a*) those in which the mode of origin of the branches is regularly dichtomous, and (*b*) those in which it is lateral or irregular. The regular genera are as yet exclusively Skiddaw-Arenig forms. The irregular genera range from the Cambrian to the middle of the Llandeilo. The former group claims the highly complex genus *Loganograptus*, Hall, the horizontal distribution of which is world-wide. To the latter group belongs the most ancient genus of the Dichograptidæ—the genus *Bryograptus*, Lapw., which is supposed to be exclusively characteristic of the *Olenus*-beds of the Upper Cambrian.

Family v. **Phyllograptidæ.**

I take this family next in order, from its undoubted relationship to the foregoing, and from its general similarity in geological distribution. Its single genus appears to be restricted exclusively to strata of so-called Arenig age. None of its species are known to occur above or below the provisional limits assigned to this formation in any of the widely separated regions where they have been recognized hitherto. The genus culminates along the same general zone of the typical Skiddaw-Arenig as its ally *Tetragraptus*; but instead

of characterizing a single subdivision only, it has a vertical range at least as extensive as that of the entire formation itself. The oldest form hitherto detected was collected by Mr. Hopkinson in the lowest zones of St. David's. The youngest species occur in profusion in the *Phyllograptus*-beds (Upper Arenig) which overlie the *Orthoceras* Limestone of Scania.

Family vi. **Diplograptidæ.**

This family is especially remarkable for the great extent of its vertical range. Its most ancient examples occur at the very threshold of the Ordovician; and its latest species do not finally disappear until we reach the summit of the first division of the Silurian proper.

It is difficult to fix upon the exact horizon where this family attains its greatest numerical expansion. In the Upper Llandeilo and in the Lower and Upper Bala it is equally prolific in individuals; several local horizons in each of these three subdivisions could be instanced where examples are so abundant that they almost hide the faces of the beds from sight. In the earlier Arenig and Lower Llandeilo individuals are of comparatively rare occurrence. In the later Lower and Middle Llandovery, though they are less abundant as a rule than in the Llandeilo-Bala strata, they nevertheless dispute the pre-eminence with the Monograptidæ. In the succeeding Tarannon or Gala-Llandovery, specimens are generally few and far between. In the Wenlock and Ludlow formations they are wholly wanting.

Diplograptus &c.—The two most important genera of the family (*Climacograptus* and *Diplograptus*) agree in their vertical range with the entire family, appearing, culminating, and disappearing together. It is impossible to decide which is the more abundant. In the Bala rocks the numerical excess in species probably belongs to *Diplograptus*, in individuals to *Climacograptus*.

Of species, the form identified by myself with *Diplograptus foliaceus*, Murch., has probably the most extended vertical and horizontal distribution. It is found in abundance everywhere in higher Llandeilo and Lower Bala strata. In the Lower and Upper Bala its place is taken by *D. truncatus*, Lapw.

The subgroups *Cephalograptus*, Hopk., *Petalograptus*, Suess, and *Dimorphograptus*, Lapw., are all exclusively Llandovery in range. The beautiful forms *Cephalograptus cometa*, Geinitz, and *Petalograptus folium*, His., mark the middle zones of the Valentian throughout Western Europe and Britain.

Of the genus *Climacograptus*, Hall, perhaps *Climacograptus bicornis*, Hall, is the most widely distributed. It agrees precisely in its vertical range with *Diplograptus foliaceus*, Murch.

The conventional genus *C. scalaris*, His., sp., unites by its so-called varieties the Ordovician and Silurian systems. They make their appearance in the Middle Bala, and die out in the higher Llandovery.

Cryptograptus.—The genus *Cryptograptus*, Lapw., is unknown above the Bala Limestone. Forms allied to *Cryptograptus tricornis*, Carruthers, are abundant in the Glenkiln zones.

Family vii. **Lasiograptidæ** (or **Glossograptidæ**).

We now enter upon very unsafe palæontological ground. The family of the Lasiograptidæ is merely an assemblage of diprionidian genera, certainly more closely allied among themselves than they are, on the one hand, to the typical Diplograptidæ, and, on the other, to the forms at present grouped in the Retiolitidæ. They agree with the former in their general external features and in the continuity of the epiderm, while they differ from them in certain details of internal structure, and in the form and position of the reproductive processes. In these latter respects they agree with typical Retiolitidæ.

Retiograptus, Hall.—The oldest genus referable to this family is the peculiar form *Retiograptus* of Hall, which appears to combine in its polypary the marginal meshwork of *Lasiograptus* and the lateral spurs of *Glossograptus*. Only two forms are known, and both are of Arenig age. One, *R. tentaculatus*, Hall, occurs in the Quebec group; the other has been figured by Mr. R. Etheridge, Jun., from the corresponding beds in Australia.

Glossograptus, Emmons.—This genus ranges from the base of the Arenig to the horizon of the Bala Limestone. Its peculiar forms are very abundant on certain horizons in the Llandeilo of Sweden. In Britain it is usually a rare fossil.

Lasiograptus, Lapw.—This genus (which includes only those forms in which the reproductive sacs appear to have been protected by a continuous series of marginal meshes) has not hitherto been quoted from Arenig rocks. It is abundant in the Upper Bala, above which it is unknown.

Hallograptus, Carr.—The title of *Hallograptus* was suggested by Mr. W. Carruthers for forms like *Diplograptus? bimucronatus*, Hall, in which the gonosome is provided with scopulate reproductive processes. The genus as thus defined is strictly Llandeilo-Bala in range on both sides of the Atlantic.

Family viii. Retiolitidæ.

Of all the families of the Rhabdophora this has the greatest vertical extension. Its known range extends from the base of the Ordovician to the middle of the Silurian proper. It must, however, like the previous family, be regarded as being essentially an artificial group, including genera of very uncertain zoological relationships.

Trigonograptus, Nich.—The oldest of the genera provisionally referred to this family is the genus *Trigonograptus*, Nich., with very thin continuous or punctate epiderm and faintly marked-off hydrothecæ. It is purely an Arenig genus.

Gymnograptus, Tullberg.—This is certainly most intimately allied to the foregoing, standing in some respects between it and the typical Lasiograptidæ. It is abundant in Scania, in the Llandeilo beds, but has not hitherto been recognized in Britain.

Clathrograptus, Lapw.—Is one of the rarest of fossils in the Llandeilo-Bala (Glenkiln) of Scotland and New York. Its relationship to the strange complex form *Retiograptus eucharis*, Hall (Grapt. Quebec Group, pl. xiv. fig. 9), is probable, but uncertain.

Retiolites.—The genus *Retiolites* proper (*Gladiolites* or *Gladiograptus*), with its reticulate periderm and faintly-marked thecal walls, ranges from the Lower Bala into the Upper Wenlock.

The only known Ordovician example of the genus (*Retiolites* (*Neurograptus*) *fibratus*, Lapw.) is remarkable for its strong central virgula. Its gonosome is furnished with lateral reproductive appendages (scopulæ), similar to those of *Hallograptus*, Carr.

Retiolites Geinitzianus is the most widely distributed species of the family. In Britain it ranges from the base of the Tarannon to the higher Wenlock, and is a common and characteristic fossil in the corresponding strata in Scandinavia and Central and Southern Europe.

Part IV. Conclusion.

We have now completed our survey of the available data bearing upon the distribution of the Rhabdophora in space and time, and of the more important conclusions to which they appear to point. It only remains, finally, to indicate the chief propositions which these results seem to place outside the pale of future controversy, or render so highly probable that they may be provisionally accepted as true.

The novelty and complexity of the subject constitute a sufficient apology for the multiplicity of the evidences brought forward in the earlier portion of this paper, and for the detailed indication of the several results that may safely be deduced therefrom. The widespread disbelief in the value of the Graptolite as a geological index is hardly likely to be overthrown by any thing short of a perfect demonstration of the contrary opinion. I have therefore felt it necessary to adduce all the more important facts and arguments which appear to me to substantiate my views, that the evidences may be weighed collectively and in detail by each student for himself personally, and the way cleared for a new and more correct departure in this regard.

Our present knowledge of the details of the physical and palæontological succession of the British Proterozoic rocks is admittedly superficial. Much painstaking and extended research is necessary before we shall be prepared to say with confidence what are their most natural subdivisions, and what are their special and peculiar fossils. That some of our rock-formations will be found in future to be of far greater value in the geologic scale than is now admitted is tolerably certain; but, at present, it is impossible to guess either in what respects our received classification is deficient, or what groups have been ignorantly assigned an exaggerated and unnatural importance.

Nor is the zoological department of our subject less tentative and imperfect. The absence in the fossil Graptolites of those soft parts of the animal which are of such primary importance in the determination of the inter-relationships of their modern allies among the Hydrozoa, forces us to rely exclusively upon elements of classification derived from the less-reliable peculiarities of their hard skeletons. This gives a character of uncertainty to our schemes of arrangement, which is felt most keenly by the graptolithologist, as he is forced to look upon his larger divisions as only doubtfully permanent in their composition and gradation. On the other hand, his smaller groups, which, from his special training are to him more a matter of instinct than of logical demonstration, are less easy of acceptance by the average palæontologist, who, recognizing the simplicity in structure and close resemblance in externals among all the Rhabdopora, looks upon the minute criteria by which the graptolithologist classifies his families, genera, and species as being frequently trivial in character and not always available in application.

In all these respects our two scales (the geological and the zoological) are pretty much upon a par. In both we recognize

a few major divisions of wide extent and vague limits. In both we find these larger sections subdivided into a series of minor groups, more rigidly defined, separable in their turn into still smaller sections of strata, or grouplets of life-forms, the comparative importance of which varies within certain very small limits dependent upon local convenience or personal equation. In both, however, if we eliminate all the controverted matter and have respect merely to acknowledged facts, enough remains to satisfy us that many of the grander outlines of our subject are even now clearly discernible. Future investigation must take origin from our present standpoint. While, therefore, much will long remain a matter for individual opinion, it may be expected that future research will tend mainly to give clearness and completeness to our present schemes of classification, repairing their deficiencies by the intercalation of new members, and substituting the definiteness of exact knowledge for the vagueness of partial ignorance and provisional opinion.

Of the imperceptible but ceaseless growth of this clearer knowledge we have an instance in the present study, which has served to bring insensibly into prominence many facts pointing to a more convenient grouping of the Rhabdophora themselves than that hitherto in use among palæontologists. Having regard to the most probable alliances and geological distribution of the various genera of the Rhabdophora recognized to this date, we find that they are most satisfactorily classified for the purposes of comparison in four main groups, each of which is composed of an association of allied genera, in which the polypary is constructed of a fundamental and special element or elements variously combined. The first group may be said to consist of simple and complex forms of the genus *Monograptus*; the second of variously modified forms of the biserial genus *Diplograptus*; the third of simple, complex, and compound modifications of the bilateral genus *Didymograptus*; and the fourth of similar variations of the genus *Dicellograptus*.

The most circumscribed of these groups (Monograpta) is composed solely of the family of the Monograptidæ. The great systematic importance of this family clearly entitles it to divisional rank. It is the only section of the Rhabdophora in which all the component genera possess both unilateral and uniserial polyparies. To this section Hopkinson's title of Monoprionidæ should in future be restricted.

The second group (Diplograpta), which is founded on *Diplograptus* as a type, and includes the three families of the Diplograptidæ, Lasiograptidæ, and Retiolitidæ, has the

longest vertical range, and claims the most varied forms of the Rhabdophora. It is the only division in which all the families have biserial or diprionidian polyparies; and to this section alone the title of Diprionida can be properly applied.

The third group (Didymograpta) finds its type in the genus *Didymograptus*, and includes all the genera at present arranged in the two families of the Dichograptidæ and Phyllograptidæ, according as their polypiferous branches are free or conjoined. The form of the calycle and the mode of growth of the polypary in all these genera is essentially similar; and they appear to be most naturally grouped in one and the same primary division. The calycle is a conical sac expanding outwards toward the aperture, which opens outwardly, well outside the ventral margin of the polypary; while in all the typical genera the sicular angle is the wider or outer "angle of divergence." Hence we may suggest for them the alternative title of the "Exoprionida."

Finally we have a fourth section (Dicellograpta), which includes the families of the Dicranograptidæ and Leptograptidæ, and of which the genus *Dicellograptus* is emphatically the type. In all its component genera the calycle is free, narrow, and flattened inwards upon the cœnosarcal canal, and the aperture opens inwards either wholly (Dicranograptidæ) or in part (Leptograptidæ) within an excavation dug in the ventral margin; while the sicular angle is invariably the smaller or inner angle of divergence. To this group, therefore, the discretionary title of Endoprionida may be conveniently applied.

Turning next to our geological scale of the Lower Palæozoic rocks, we see that it is composed of the three grand rock-systems of the Cambrian, Ordovician*, and Silurian, the boundaries of the middle system alone being defined with tolerable exactness. The fossiliferous portion of the Cambrian, again, is provisionally separable into a Lower or Paradoxidian division, and an Upper or Olenidian division. The Ordovician falls most naturally into two main divisions—a Lower or Arenig division, and an Upper or Bala division—the line of demarcation between them passing through the middle of the so-called Llandeilo formation. Lastly, the Silurian is most conveniently regarded as being composed of three members—a Lower or Llandovery-Tarannon (Valentian) division, a Middle or Wenlock-Lower-Ludlow (Salopian) division,

* I have employed the title of *Ordovician* for the Lower Silurian of Murchison throughout the whole of this paper for the sake of uniformity. I prefer, however, the shorter and more euphonious title of *Ordovian*, which I have generally employed elsewhere. (C. L.)

and an Upper or Upper-Ludlow-Downton (Downtonian) division.

Subordinate to these are the formations and subformations generally recognized among geologists.

Placing these zoological and geological scales in juxtaposition (see Table XI.), we recognize immediately that most intimate correspondence between life-type and time-epoch which is inevitable upon any theory of gradual evolution. Our grandest zoological groups do not, it is true, fit in individually with the several rock-systems; but the time-ranges of our chief generic types admit of rigid localization and admeasurement upon our geological scale, and form a series which may be paralleled with that of our recognized subformations with wonderful accuracy. On a general review of all these correspondences, as detailed in the foregoing pages, it is evident that they establish the following propositions:—

(i.) The Rhabdophora, or true Graptolites, are exclusively Lower-Palæozoic fossils, coming into visible existence in the Upper Cambrian, and disappearing from sight in the Upper Silurian.

(ii.) They attain their maximum, both in genera and species, about the middle of this range, *i. e.* in the Llandeilo formation; and there is a gradual decrease in forms in proportion as we pass upwards or downwards from this horizon.

(iii.) The three grand groups of the Didymograpta, Dicellograpta, and Monograpta are so restricted in their vertical range that each distinguishes a certain portion of the ascending succession of formations. The Didymograpta are essentially Lower-Ordovician fossils, the Dicellograpta Upper-Ordovician, while the Monograpta are confined exclusively to the Silurian proper.

(iv.) With but two exceptions, each of the families of the Rhabdopora ranges through a fraction only of the entire succession of the Lower Palæozoic rocks, nowhere exceeding in vertical extent that of an entire system. The Dichograptidæ are Upper-Cambrian and Lower-Ordovician fossils; the Phyllograptidæ are exclusively Arenig; the Leptograptidæ and Dicranograptidæ are essentially Upper-Ordovician; while the Lasiograptidæ are as rigidly confined to the Ordovician itself as the Monograptidæ are to the succeeding Silurian.

(v.) Among the genera this limitation in time is carried out even more minutely. *Loganograptus*, *Tetragraptus*, *Dichograptus*, *Retiograptus*, and several others are exclusively Arenig genera. *Pleurograptus*, *Amphigraptus*, *Cœnograptus*, &c. are peculiar to the Bala. *Rastrites* distinguishes the Valentian, and *Cyrtograptus* the Salopian.

TABLE XI. Showing the Vertical Distribution of the Tribes, Families, and Genera of the Rhabdophora in the chief Graptolite Zones of the Lower Palæozoic Rocks.

	Cambrian.	Ordovician.									Silurian.										
		Lower.			Upper.						Lower.						Middle.				
		Arenig.		Llandeilo.	Caradoc.						Llandovery.			Tarannon.			Wenlock.			L. Ludlow.
	1. *Bryograptus* zone.	2. *Tetragraptus* zone.	3. *Didymog. bifidus* z.	4. *Didymog. Murchisoni* z.	5. *Cœnog. gracilis* z.	6. *Dicranog. Clingani* z.	7. *Pleurog. linearis* z.	8. *Dicellog. complanatus* z.	9. *Dicellog. anceps* z.	10. *Diplog. acuminatus* z.	11. *Diplog. vesiculosus* z.	12. *Monog. gregarius* z.	13. *Monog. spinigerus* z.	14. *Rastrites maximus* z.	15. *Monog. crigus* z.	16. *Cyrtog. Grayæ* z.	17. *Cyrtog. Murchisoni* z.	18. *Cyrtog. Lumarssoni* z.	19. *Monog. testis* z.	20. *Monog. Nilssoni* z.
Section A. MONOGRAPTA (MONOPRIONIDA).																					
Family I. **Monograptidæ.**																					
Genus 1. Rastrites, *Barr.*												*	*	*	*						
2. Cyrtograptus, *Carr.*																*	*	*	*	*	
3. Monograptus, *Geinitz*											*	*	*	*	*	*	*	*	*	*	
Section B. DICELLOGRAPTA (ENDOPRIONIDA).																					
Family II. **Dicellograptidæ.**																					
Genus 4. Dicellograptus, *Hopk.*			*	*	*	*	*	*	*												
5. Dicranograptus, *Hall.*					*	*															
Family III. **Leptograptidæ.**																					
Genus 6. Amphigraptus, *Lapw.*						*	*														
7. Pleurograptus, *Nich.*							*														
8. Leptograptus, *Lapw.*					*	*	*														
9. Cœnograptus, *Hall*					*																
10. Azygograptus, *Nich.*		*	*																		

Section C. Didymograpta (Exoprionida).																				
Family IV. **Dichograptidæ.**																				
Genus 11. Didymograptus, *M'Coy*		*	*	*	*															
12. Tetragraptus, *Salt.*		*																		
13. Dichograptus, *Salt.*		*																		
14. Loganograptus, *Hall*		*																		
15. Clonograptus, *Hall*	*	*																		
16. Clematograptus, *Hopk.*		*																		
17. Temnograptus, *Nich.*		*																		
18. Trichograptus, *Nich.*			*																	
19. Schizograptus, *Nich.*		*																		
20. Goniograptus, *M'Coy*		*																		
21. Bryograptus, *Lapw.*	*																			
Family V. **Phyllograptidæ.**																				
Genus 22. Phyllograptus, *Hall.*		*	*																	
Section D. Diplograpta (Diprionida).																				
Family VI. **Diplograptidæ.**																				
Genus 23. Diplograptus, *M'Coy*		*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Subgen. Cephalograptus, *Hopk.*														*						
Dimorphograptus, *Lapw.*												*	*							
24. Climacograptus, *Hall*		*	*	*	*	*	*	*	*	*	*	*	*	*	*					
25. Cryptograptus, *Lapw.*		*	*	*	*															
Family VII. **Lasiograptidæ.**																				
Genus 26. Retiograptus, *Hall.*		*																		
27. Glossograptus, *Emmons*		*	*	*	*															
28. Hallograptus, *Carr.*					*															
29. Lasiograptus, *Lapw.*					*	*														
Family VIII. **Retiolitidæ.**																				
Genus 30. Trigonograptus, *Nich.*		*	*																	
31. Gymnograptus, *Tullb.*					*															
32. Clathrograptus, *Lapw.*					*															
33. Retiolites, *Barr.*						*	*						*	*	*	*	*	*		

(vi.) Descending to the species of Rhabdophora we find that instead of ranging through enormous thicknesses of rock, as hitherto supposed, they are so restricted in vertical distribution that few have a more extended range than that which is covered by a single formation in the vertical series; while the vast majority are peculiar to a single subformation, or mark certain special horizons outside of which they are wholly unknown. As might have been anticipated, the forms which have the greatest longevity present us with the greatest number of recognizable varieties, while the species of shorter range rarely show any notable departure from the primitive type.

(vii.) The ascertained restriction of the divisions, families, and genera of the Rhabdophora in time necessarily gives to the collective Graptolitic fauna of each of the subsystems or major formations of the Lower Palæozoic rocks a special and distinctive aspect that renders it capable of immediate identification all over the world. The Arenig division is recognizable at a glance by its crowds of Phyllograptidæ and Dichograptidæ; the Bala by the absence of these families and the presence of multitudes of Dicellograpta and Diplograptidæ; the Valentian by the absence of the former and the presence of the latter in association with Monograptidæ; and the higher Silurians by the absence of the Diplograptidæ and the presence of Monograptidæ alone.

(viii.) The further restriction in time and vertical extension of the species and varieties of the Rhabdophora places in our hands the material available for a more minute subdivision of the formations of the Lower Palæozoic rocks than has hitherto been attempted. These subdivisions or Graptolite horizons answer roughly to the Ammonite zones of the Jurassic rocks of Europe, and will, in all probability, prove of equal value in the correlation of widely separated deposits. At present the following zones are recognizable, many of them of extraordinary geographical range:—

Upper Cambrian.

1. *Zone of* Bryograptus Callavei, *Lapw.*—In the Upper Cambrian we know as yet only a single Graptolitic zone, that of the *Olenus*-beds of Scania and their extra-Scanian representatives. It may be termed the zone of *Dichograptus* (?) *tenellus*, Linnrs., or *Bryograptus Callavei*, Lapw. As I have already indicated, we are almost totally ignorant of the details of its Graptolitic fauna. It seems to be characterized, however, by similar forms of Dichograptidæ in Scania, Norway, Shropshire, and the Malvern Hills.

Lower Ordovician.

2. *Zone of* Tetragraptus (bryonoides, *Hall*).—This is the typical Quebec or Skiddaw Graptolite zone. It is strikingly individualized by the exclusive possession of all the known forms of the genus *Tetragraptus*, Hall. The genera *Loganograptus*, Hall, *Clonograptus*, H., *Schizograptus*, Nich., and *Dichograptus*, Salt., are all probably peculiar to this zone, as are also the species *Didymograptus extensus*, Hall, *D. pennatulus*, Hall, and the only known examples of *Retiograptus*, Hall. This zone is recognizable at St. David's, Shelve, Skiddaw, Norway, Scania, and in North America and Australia, everywhere distinguishable by the same group of forms.

3. *Zone of* Didymograptus bifidus, *Hall.*—This zone finds its typical representative in the Upper Skiddaw beds of the Lake District and in the "*Phyllograptus* beds" of Scania. It is most especially marked by the presence of *Phyllograptus*, in association with geminiform *Dichograpti* of the group typified by *D. bifidus*, Hall. From the zone below it is distinguishable by the extreme rarity of compound Dichograptidæ. Its peculiar fossils are *D. bifidus*, Hall, *D. minutus*, Tullberg, and some forms of Diplograpta, such as *Climacograptus confertus*, Lapw. Many of its commonest forms in Britain appear to be survivals of those of the underlying zone, such as *Phyllograptus angustifolius*, H., *P. typus*, Hall, *Didymograptus patulus*, Hall, *D. affinis*, Nich., *D. Nicholsoni*, Lapw., &c. The zone has been identified at Llavirn near St. David's, at Tyobry, at Shelve, in Cumberland, and in Scania and Dalarne.

4. *Zone of* Didymograptus Murchisoni, *Beck* (geminus, *His.*).—This is the typical Upper-Llandeilo Graptolitic zone of Murchison, but both physically and palæontologically it appears to be most distinctly allied to the foregoing Upper Arenig zone. It is characterized mainly by the exclusive presence of the form which gives it its name, by the total absence of the genus *Phyllograptus*, and by a few distinctive Diplograpta, of which the best-known is *Climacograptus cœlatus*, Lapw.

The zone is recognizable by position, mineralogical character, and fossils in Britain at Llandeilo, Builth, Shelve, Abereiddy, Pont Seiont, in Scandinavia near Christiania, in Scania, and in Brittany and Portugal.

Upper Ordovician.

In Wales the Upper Ordovician is separated from the Lower by a series of grits and trap-rocks with possible uncon-

formity. Of the very lowest beds of the Upper Division we as yet know little with certainty. The deepest zone recognizable at the present time is the

5. *Zone of* Cœnograptus gracilis, *Hall* (*or* of Dicellograptus sextans, *H.*).—This is typically developed in the lower portion of the Glenkiln shales of the south of Scotland. It is the first of the Dicellograptidian zones, and is well particularized by the peculiar genus *Cœnograptus.* Only a single Dichograptid (*D. superstes*, Lapw.) survives. Dicranograptidæ are abundant, *Dicranograptus ziczac*, Lapw., *D. formosus*, Hopk., *Dicellograptus sextans*, Hall, *D. intortus*, Lapw., are peculiar, and several Diplograpta, such as *Hallograptus bimucronatus*, Nich., *H.*? *mucronatus*, Hall, *Diplograptus Whitfieldi*, H., &c. This zone was first recognized by Hall in the Normans-Kill beds of the valley of the Hudson. In Britain it occurs near Builth, at Portmadoc; in Scandinavia in the Middle Graptolite schists of Scania; and, in all probability, also exists in the Ordovician rocks of Australia.

6. *Zone of* Dicranograptus Clingani, *Carr.*—This includes the dark shales that are supposed to underlie the Bala Limestone of North Wales, and finds its most perfect type in the Lower Hartfell shales of the south of Scotland. Its peculiar forms are *Dicranograptus Clingani*, Carr., *Dicellograptus Forchammeri*, Geinitz, *Lasiograptus Harknessi*, Nich. It is well developed at Conway, North Wales, at Moffat (Lower Hartfell), at Girvan, in the north of Ireland, in Scania at many localities, and in the lower beds of the Lorraine shales of North America.

7. *Zone of* Pleurograptus linearis, Carr.—This zone in all probability includes the horizon of the Bala Limestone of North Wales and of its equivalent the *Chasmops* Limestone of South Sweden. It is remarkable in Scotland for the abundance of Leptograptidæ it affords, the genera *Amphigraptus* and *Pleurograptus* being almost strictly confined to this zone. Its peculiar Moffat forms are *Leptograptus capillaris*, Carr., *Amphigraptus divergens*, Hall, *Diplograptus quadrimucronatus*, Hall, *Climacograptus tubuliferus*, Lapw., all of which, with their Moffat associates, mark the same zone in Girvan, in County Down, at Rostånga in Scania, and apparently also in the Hudson-River group of North America.

8. *Zone of* Dicellograptus complanatus, *Lapw.*—The strata that lie between the zone of *P. linearis*, Carr., and the summit of the Ordovician system form in South Scotland two very distinct zones, though few Rhabdophora have yet been described from them. The lowest zone is that of *Dicellograptus complanatus*, Lapw., which contains but few peculiar

forms in addition to its characteristic species. It is recognizable in the same stratigraphical position and affording the same fossils at Moffat (Barren Mudstones), at Girvan, in County Down, at Rostånga in Scania in the lower part of the *Trinucleus*-schist, and in Westrogothia.

9. *Zone of* Dicellograptus anceps, *Nich.*—The final zone of the Ordovician system is everywhere characterized by *D. anceps* in the Moffat area and in the district of Girvan (Drummuck beds). According to Dr. Tornquist it holds the same place and fossils in the *Trinucleus*-beds of Dalarne.

Silurian System.

10. *Zone of* Diplograptus acuminatus, *Nich.*—This is the oldest recognizable zone of the Silurian in the Moffat area, where there is no physical line of demarcation at the summit of the Ordovician. In Girvan, where the line of separation is most strongly marked, the same zone is still recognizable. Its palæontological characters, so far as the Rhabdophora are concerned, are decidedly negative. The Dicellograpta have become extinct, and the Monograpta have not yet appeared. The only forms present are Diprionida. *Diplograptus acuminatus* and *Climacograptus normalis*, Lapw., mark the zone in Moffat and in Girvan. In Sweden it includes the typical beds of the Brachiopod schists, which are similarly marked by an abundance of *C. normalis*, unaccompanied by members of other Graptolitic families.

11. *Zone of* Diplograptus vesiculosus, *Nich.*—This must be regarded in the light of an introductory zone to the following. In the typical region of Moffat it contains an abundance of the fossil which gives it its name, together with the first forms of Monograptidæ (*M. tenuis*, Portlock, and *M. attenuatus*, Hopk.). It includes the Lower *Pentamerus* Limestones of Girvan, and has been identified in the north of Ireland.

12. *Zone of* Monograptus gregarius, *Lapw.*—Whether we have respect to the abundance and variety of its Graptolitic fauna or to the wide geographical range, this zone must be considered the most important in the Llandovery rocks. In the Birkhill area it is capable of division into two subzones—the lower marked by the presence of *Monograptus triangulatus*, Harkn., and the upper by the presence of *Rastrites peregrinus*, Barr. The peculiar species that distinguish the zone may be gathered from a study of Table VII. *M. gregarius*, Lapw., *M. fimbriatus*, Nich., *Diplograptus physophora*, Nich., *M. leptotheca*, Lapw., are especially characteristic. The zone yields the same fossils at Girvan, at Pomeroy and Coalpit Bay in the north of Ireland, in Bornholm,

at Tosterup in Scania, in Westrogothia, and in the schists of Dalarne—in Thuringia, Bohemia, the Eastern Alps, France, and Spain.

13. *Zone of* Monograptus spinigerus, *Nich.* (Sedgwicki, *Portlock*).—This zone overlies the former throughout the greater part of its extended geographical range; and the fossils of both have been intermingled in published lists. It is distinguished from the *M.-gregarius* zone by the presence of *M. spinigerus*, Nich., *M. Hisingeri*, Carr., *M. intermedius*, Carr., *M. argutus*, Lapw., *Diplograptus cometa*, Geinitz, *D. palmeus*, Barr., &c. It is recognizable in the Moffat and Girvan areas, in Ireland at Pomeroy, in the Coniston Mudstones, at the Devil's Bridge, Cwn Symlog, &c. in Mid Wales, at Kongslena in Westrogothia, &c.

14. *Zone of* Rastrites maximus, *Carr.*—In many respects this must be regarded as the zone of transition into the succeeding formation. Its fauna is essentially a compound of that characteristic of the more strikingly separated beds above and below. It ought in all probability to be regarded as forming the base of the Tarannon group. Its most striking species are *Rastrites maximus*, Carr., and *Monograptus crassus*, Lapw., the first of the forms of the type *M. priodon*, Bronn. The zone has a wide range in South Scotland, and has been doubtfully recognized in Mid Wales, Scania, and Dalarne.

15. *Zone of* Monograptus exiguus, *Nicholson.*—This is the typical Tarannon or Gala zone of Britain. The thin graptolitiferous seams found occasionally in the thick zones of flagstones and purple-and-green shales of this formation are often matted with entangled groups of the characteristic form of the zone. *M. galaensis*, Lapw., *M. crispus*, Lapw., *M. turriculatus*, Barr., *M. Salteri*, Lapw., are generally peculiar. The remainder are survivors from the Birkhill zones or forerunners of the Wenlock-Ludlow fauna. Of the latter, *Retiolites Geinitzianus* is very rare, while varieties of *M. priodon* are common.

The zone is typified by the Lower Gala series of South Scotland and the *Crossopodia* beds of Girvan. It is recognizable in Ireland in the shales of Tieveshilly, in Wales in the Tarannon shales of Conway, and in the Lake District in the Knock beds. It has been recognized by Dr. Tornquist in Dalarne; its fossils have been detected by Mr. Linnarsson at Motala in Ostrogothia and elsewhere. It seems to be present also in Thuringia and Bohemia.

16. *Zone of* Cyrtograptus Grayæ, *Lapw.*—The upper division of the Gala group is marked off from the lower division

by the total absence of Diplograptidæ, and by the presence of many Wenlock forms, such as *Monograptus vomerinus*, *M. riccartonensis*, &c. Strata with a similar transitional fauna occur in Girvan, and form the earlier zones of Tullberg's *Retiolites* Skiffar in Scania (Tullberg, Geol. För. Förh. 1880, N. 59, B. 5. N. 3).

Wenlock-Ludlow Series.

17. *Zone of* Cyrtograptus Murchisoni, *Carr.*—The base of the Wenlock series of Builth is formed by a highly fossiliferous series of shales crowded with *C. Murchisoni*, *M. vomerinus*, Nich., and a few survivals of the Grieston fauna. The same fossiliferous zone has been met with in Shropshire, in the valley of the Dee, North Wales, in Denbighshire, and more doubtfully in the Lake District. It is well developed in the succession at Rostånga in Scania, and is present also in Bohemia.

18. *Zone of* Cyrtograptus Linnarssoni, *Lapw.*—The Wenlock shales of Shropshire have not yet been minutely separated into their natural divisions; but two fairly distinct zones are already recognizable in their British or foreign equivalents. To the lowest of these zones belong the strata near Builth which succeed the *C.-Murchisoni* beds, and afford *C. Linnarssoni*, Lapw., and a few other peculiar forms. It is possible that the *C.-Carruthersi* bands of the Riccarton beds of South Scotland belong to this general horizon; but as yet the typical *Cyrtograptus* has not been detected within them. The middle beds of the *Cyrtograptus* Skiffar of Scania have a corresponding Graptolite fauna.

19. *Zone of* Monograptus testis, *Barr.*—In the highly prolific graptolitiferous rocks of the south of Sweden the highest zone that can with certainty be assigned to the equivalents of the British Wenlock shales is characterized by the beautiful form *Monograptus testis*, Barr. Its commoner associates are abundant forms in the Wenlock of Britain; but the typical fossil itself has not hitherto been detected here. The zone is recognizable in Bohemia, Thuringia, and France.

20. *Zone of* Monograptus Nilssoni, *Barr.*—The highest and most important graptolitic zone of the Wenlock-Ludlow formation is that which lies between the Wenlock and Aymestry Limestones of Siluria and forms the Lower Ludlow shales of Murchison. Its beds are of great thickness both in Britain and Scandinavia, and will probably in the future be found divisible into several distinct zones. This is shown by its collective fauna, which is specifically very distinct from that of the Wenlock shales. The most prolific form of the zone

is the *M. colonus* (of authors), which is peculiar, as also are *M. Rœmeri*, Barr., *M. scanicus*, Tullberg, and many others. This zone is magnificently developed in Britain and in the south of Sweden, and is recognizable in Norway, Bohemia, Bretagne, and the south of France.

It is not pretended that each of the so-called zones enumerated above is of equal geological importance. The zones of *Tetragraptus* (2), *Didymograptus geminus* (4), *Cœnograptus gracilis* (5), *Monograptus gregarius* (12), and *Monograptus Nilssoni* (20) are of such paramount consequence, whether we consider the thickness of their included strata in Britain, or the great variety and wide geographical range of their distinctive faunas, that they deserve rather the titles of subformations. On the other hand, two or three zones, notably those of *Diplograptus vesiculosus* (11) and *Cyrtograptus Linnarssoni* (18), must, in the present state of our knowledge, be regarded merely as provisional stages, distinguished locally by a few peculiar forms, as yet restricted in their horizontal distribution. Again, the species which gives its name to the zone has, in one or two instances, been detected in the overlying bands, as is the case with *Monograptus gregarius*, Lapw., and more doubtfully with *M. spinigerus*, Nich.; but in these exceptional cases the species, instead of being predominant in these overlying beds, is rare and inconspicuous. But, if we have correctly interpreted the materials in our hands, it is indubitable that each of these zones marks a special substage or horizon in the ascending series of the Lower Palæozoic rocks. The formation to which it most naturally belongs is determined by the special facies of its collective Graptolite fauna; and its vertical place within that formation is fixed by its peculiar and predominant species.

This list must be regarded merely as a first attempt to define and localize the minor Graptolite faunas of these ancient sediments, and to make them available for the proposes of the geologist and zoologist, as indices of the systematic place of their containing beds, or as evidences of the mode and direction of the development of life. It may confidently be expected that future research will soon fix more definitely the composition and limits of the characteristic faunas of the zones already recognized, extending the range of some of their forms into neighbouring stages, detecting fresh criteria in their separation, and adding largely to the number of the zones themselves.

The acceptance of our conclusion that the Graptolites are as restricted in their vertical range as other and more perfectly and generally studied groups of fossils, is merely a

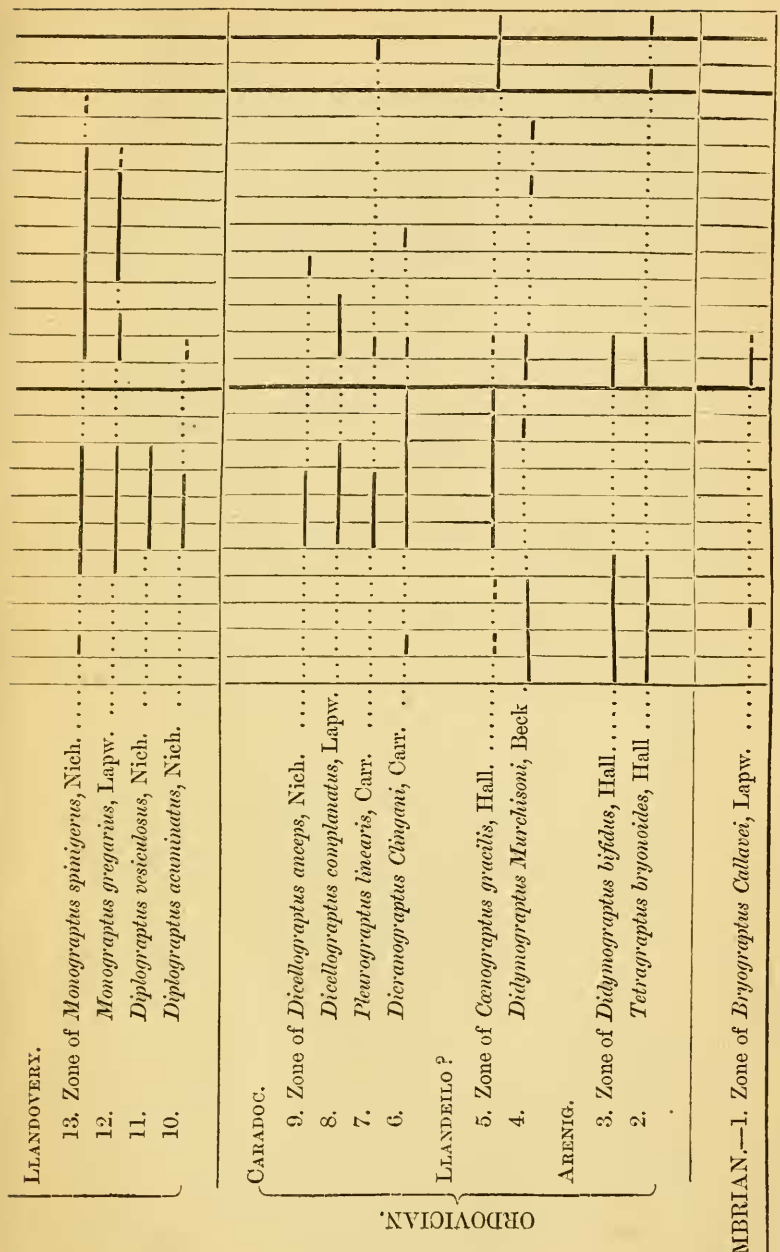
question of time; and in these zones the geologist is presented with a new and invaluable key to the elucidation of the details of the succession among the Lower Palæozoic rocks—a key of far wider application than any formerly at his command. The fossil Crustacea and Brachiopoda, on which he has hitherto been content to rely, are, as a general rule, confined to sediments containing a large proportion of carbonate of lime. The limestones and calcareous sandstones in which they occur most abundantly are usually so diversified in their petrographical characters that the working geologist is often wholly able to dispense with the aid of the palæontologist in determining the limits and inter-relationships of their containing strata. But these highly calcareous deposits constitute merely an insignificant fraction of our Lower Palæozoic sediments. The vast majority are grits, flagstones, and shales, containing a most minute proportion of calcareous matter, and from which, as a consequence, the lime-loving forms are wanting. These enormous accumulations of strata, composed of endless repetitions of similar rocks, incapable of subdivision by petrographical characters, and destitute of the special fossils upon which the palæontologist relies for guidance, the geologist has hitherto been compelled to leave undivided. The unbroken sheets of the flag-like Silurian rocks of Hereford, Merioneth, and Denbigh, which are shown upon the Survey maps in two doubtful divisions only, as contrasted with their minutely subdivided prototypes of Siluria, afford us a case in point. Other examples are seen in the wide-spreading sheets of Ordovician and Silurian strata which, unbroken by a divisional line, cover many thousands of square miles in Middle and North Wales, South Scotland, and Ireland. Now in these monotonous strata, so barren of organic remains of the higher groups, the lowly Graptolite is a frequent and characteristic fossil; and by its aid the geologist of the future will be able to read off the natural succession among these undivided sediments with ease and certainty.

(ix.) The several zones common to two or more regions occupy invariably the same relative position with respect to each other, and the same vertical place in the ascending series of formations. Hence we have no choice but to regard them as homotaxially or synchronologically identical. It will be seen from Table XII. that, as a general rule, the zones are not recognizable scattered irregularly over the globe, but that they occur more or less in groups, being restricted in their range to neighbouring geographical regions. Hence it is highly probable that we see in many of these zones the relics of what were originally special subformations or stages, once

TABLE XII. Showing the Geographical Range of the recognized Graptolitic Zones of the Lower Palæozoic Rocks.

Zone recognizable with typical fossils (————). Zone apparently present (– –).

		British Islands.											Europe.										America.		
		South-west Wales.	Middle Wales.	Shropshire.	North Wales.	Lake District.	South-west Scotland.	Moffat.	Girvan.	North Ireland.	Central Ireland.	Waterford.	Norway.	Scania.	Westrogothia.	Ostrogothia.	Dalarne.	Bornholm.	Thuringia.	Bohemia.	Bretagne &c.	South France.	Spain &c.	Canada.	United States.	Australia.
SILURIAN.	LOWER LUDLOW.																									
	20. Zone of *Monograptus Nilssoni*, Barr.			—										—						—	—	—				
	WENLOCK.																									
	19. Zone of *Monograptus testis*, Barr.													—												
	18. *Cyrtograptus Linnarssoni*, Lapw.		—										—	—	—											
	17. *Cyrtograptus Murchisoni*, Carr.		—	—	—	—								—		—	—			—						
	TARANNON.																									
	16. Zone of *Cyrtograptus Grayæ*, Lapw.						—	—						—		—	—									
	15. *Monograptus exiguus*, Nich.				—	—	—	—	—	—				—		—										
	14. *Rastrites maximus*, Carr.						—	—	—					—		—	—									


LLANDOVERY.
13. Zone of *Monograptus spiniferus*, Nich.
12. *Monograptus gregarius*, Lapw.
11. *Diplograptus vesiculosus*, Nich.
10. *Diplograptus acuminatus*, Nich.
CARADOC.
9. Zone of *Dicellograptus anceps*, Nich.
8. *Dicellograptus complanatus*, Lapw.
7. *Pleurograptus linearis*, Carr.
6. *Dicranograptus Clingani*, Carr.
LLANDEILO ?
5. Zone of *Cœnograptus gracilis*, Hall.
4. *Didymograptus Murchisoni*, Beck
ARENIG.
3. Zone of *Didymograptus bifidus*, Hall.
2. *Tetragraptus bryonoides*, Hall
ORDOVICIAN.
CAMBRIAN.—1. Zone of *Bryograptus Callavei*, Lapw.

geographically continuous, but now more or less broken up into isolated fragments. That the zones missing from the Lower Palæozoic series as developed in any single region owe their apparent absence generally to the fact that the strata have as yet been imperfectly studied, will be evident on a comparison of the Scanian column with the succession of zones as developed in Britain. The zeal and acumen of the Swedish geologists in the study of the Scanian rocks have resulted not only in the detection of all the Graptolite zones already recognized amongst us in that region, but in the discovery of several others, of the existence of which we were previously unaware. That the half-dozen zones recognizable upon the opposite side of the Atlantic were originally continuous with their British prototypes is not at all probable; but, judging from their correspondent position in the succession of formations, it may be asserted with confidence that, from a geological point of view, they answer to their representatives on this side of the Atlantic, not only in fossils but in the special epoch during which they were deposited.

(x.) In the face of these results the host of proofs formerly supposed to be afforded by the abnormalities of the vertical distribution of the Graptolithina, in favour of the doctrines of migration and colonies, vanish into thin air. These apparent evidences are now seen to have been fallacious appearances, due simply to defective knowledge. In every case where the subject is capable of proof, we have shown that the facies of the Graptolite fauna in every subformation was identical all over the Lower-Palæozoic world. We have at present no evidence whatever to show that any single Graptolite group, or even a single species or variety, made its appearance at an earlier date in one region than in another; and, as a consequence, the place of its origin and the direction of its extension in space are at present equally incapable of recognition.

The consideration of the bearing of these results upon the study of the morphological development of the Graptolites themselves demands some notice; but the subject is to a certain extent foreign to the main object of the present paper. It is enough to have demonstrated that the Graptolite appears to be as restricted in its vertical range, and as widely extended in its horizontal distribution, as any known form of life hitherto recognized as existent in Palæozoic times. Of all fossils it is the most frequent and the most widely disseminated in the rocks of that age. It is found certainly in the greatest abundance in the more carbonaceous deposits in the deeper water beds, but it is present more or less in all sediments. This is probably owing to the fact that at one stage or other of its

existence it was a free floating organism, drifting at the mercy of the winds and currents. All these circumstances conspire to render the Graptolite one of the most suitable of fossils for the purposes of the working geologist and systematist; its short vertical range affording elements for the subdivision of the accepted Lower Palæozoic formations into their component zones; its wide horizontal distribution allowing of the exact parallelism of synchronous deposits in areas now geographically separated; and its universal dissemination rendering it easy of collection and study.

CORRECTIONS.

Vol. iii. page 253. The reference in the third note (‡) should be transferred from *Retiolites* to *Didymograptus*.

Vol. iii. page 455, Table I. For (*a*) Lower Ludlow *read* (*a*) Upper Ludlow. The "Calciferous Group" should be united with the "Potsdam Group" in the Cambrian.

Vol. v. page 278, line 14 from the bottom of page, for *Tetragraptus* read *Trigonograptus*.

Vol. vi. page 19, line 12 from the bottom of page. *D. vacillans*, Tullb., is a Lower-Arenig species.

XXVI.—*On Misdirected Efforts to Conjugation in* Spirogyra. By H. J. Carter, F.R.S. &c.

[Plate XIV. A. figs. 1–3.]

Turning over the leaves of a MS. microscopical journal which I have kept since 1854, I observed figures of *Spirogyra* endeavouring to conjugate with *Cladophora*; and not being aware that any such fact has ever been published or even alluded to, it seems to me desirable that it should be publicly recorded. The material in which it occurred was obtained from a freshwater pool in the marshes of the island of Bombay, in the month of March 1854; and all that I can state respecting the species of the filamentous Algæ concerned is, that the *Spirogyra* was "double-banded," and the *Cladophora* the species usually found in the neighbourhood ? *tranquebariensis*, Kg. Accompanying the figures, however, is the following note, viz. :—

"Figs. 5, 6, 10, 11, and 12. *Spirogyra* trying to conjugate with *Cladophora*, in which the contents of the cell of the former are passing off into long root-like processes of cell-membrane applied to a filament of the latter. This was a frequent occurrence in a large basin of water wherein the *Spirogyra* and *Cladophora*, among other things, happened